The Lyme Bay experimental potting study

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A collaborative programme to assess the ecological effects of increasing potting density in the Lyme Bay Marine Protected Area

Final report

Submitted by:

University of Plymouth Marine Institute in collaboration with the Blue Marine Foundation and the local inshore fishing community

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Foreword by Charles Clover, Executive Director, Blue Marine Foundation:

It was some time in the early 1990s that people began to speak about the need to protect 'England's coral garden' - the reefs of Lyme Bay. Newspapers carried images of the rich habitats for fish, shellfish and rare species of coral and sea fans revealed below the waves. Local fishermen, conservationists, divers and anglers, among others, found themselves part of a rising chorus of concern about evidence of damage caused to the reef habitat by trawls and scallop dredges. Eventually the many local and national expressions of concern prevailed and the government chose finally to close 60 square miles of the bay to mobile fishing gears in 2008. I was privileged to be involved in a minor way in documenting that dramatic first chapter of the story, a milestone in nature conservation and the management of inshore fisheries in Britain, in my former role as environment editor of the Daily Telegraph. What I will call the second chapter of the story, documented here, began shortly after the formation of our new charity, the Blue Marine Foundation, in 2011 when we at BLUE came to Lyme Bay to hear how things were going in what had become, in effect, Britain's largest multi-use marine national park. Though by then there was evidence that the reef habitats were recovering, all was not going as well as expected for the environment or for the static-gear fishermen still entitled to fish there. Despite the original Statutory Instrument and the subsequent designation of some 90 square miles as an EU Special Area of Conservation the place didn't yet appear to be being managed to the satisfaction of either fishermen or conservationists. The prohibition of dredging and bottom-trawling had the unexpected effect of making the reefs a magnet for a concentration of static gear - pots and nets – because the static gear no longer got towed away by the mobile gear, so the closed area was a safe place to leave it to work. Was there an impact from this over-concentration of fishing gear upon some local fishermen's landings? Some said their landings had halved in recent times. We were concerned that, as this was happening, there might also be an impact upon the corals, sea fans and other benthic life that was supposed to have been protected by the closure to mobile gears. This report confirms that our suspicions were correct: that unregulated, high levels of sustained potting effort could impact some of the reef's distinctive marine life. The study also tested the assertion, from fishermen in the four ports, that their small-boat methods were sustainable but those of larger boats from outside the area were not. These results provide evidence that the current way of life for small-boat pot fishermen operating in the Lyme Bay and Torbay Special Area of Conservation (SAC) is consistent with its objectives. A maintenance of the status quo should ensure long term sustainability of this fishery.

Back in 2012, BLUE and the fishermen agreed to set up a Consultative Committee and to try to achieve three 'wins' for fishing and conservation:

1) A win for the fishermen to provide them and their heirs with a sustainable living;
2) A win for conservation in the protection of the Lyme Bay ecosystem and its stocks of seafood;

3) A win for the communities around the bay.

But how were we to measure success? Particularly in achieving the crucial second aim, on which everything else depended? We wanted to guarantee the fishermen from the four local ports what they wanted, a right of access to the resource as long as it could be proved that what they were doing was sustainable. Nobody could tell us, however, what density of potting that was and what level would impact not only the target species of lobster and crab but damage the reefs and their corals. Luckily, Dr Bob Watson who was then chief scientist at Defra was persuaded that this was precisely the kind of information that would be valuable as Britain developed its network of marine protected areas, most of which would continue to be fished. So, the potting study began – with a secondary aim of seeing if there were any ’spillover’ effects beneficial to fishing from the small 500m x 500m areas where potting had been removed as control areas for the experiment (something it has not been possible to prove). The study has had its challenges: nobody anticipated all the pots and markers being washed away in the storms of the winter of 2013/14 with an impact on the seabed and data comparisons which necessitated a year’s extension to the project, but we are delighted that it has had some clear results. These show a ‘threshold’ at which fishing effort begins to be damaging to crustacean populations and the reef environment. We did not anticipate the other fascinating finding: that lower effort would result in a higher quality of catch. This completely vindicates the ‘high quality, low volume’ fishery the Lyme Bay Fisheries and Conservation Reserve has tried to encourage in its voluntary code of conduct. We did not anticipate such clear findings and we thank Adam Rees and all at the University of Plymouth for their analyses, and the funders at Defra for their commitment to the science. These results will enable the Lyme Bay Fisheries and Conservation Reserve Consultative Committee to manage the Lyme Bay and Torbay Special Area of Conservation (SAC) with confidence into the future. These results also provide invaluable advice for the managers of other marine protected areas, both around Britain’s coasts and elsewhere.

1. Introduction

As attitudes towards marine management in the UK become more ecosystem-based, holistic approaches that favour the conservation of multiple marine resources are being championed. Marine ecosystem-based management focuses on protecting entire environments while unsustainable and damaging activities that compromise the sustainability and conservation efforts are removed (Pikitch *et al*. 2004). This approach recognises that 'humans are an integral component of ecosystems'. This means that socio-economic factors are considered alongside ecological factors to benefit fisheries by managing and protecting resources at the ecosystem level rather than at the species level (Gaines *et al.* 2010). Effectively managed marine Protected Areas (MPAs) are considered as key refuges for implementing an ecosystem-based approach. MPAs have demonstrated their efficacy at providing dual-benefits to (1) conservation, and (2) fisheries, due to their protection of marine habitats and promotion of sustainable use and conservation. This can lead to increased economic income contributing to 'blue growth', with fisheries contributing substantially, while increasing environmental protection (Roberts and Hawkins 2000; Shears *et al.* 2006; Vaughan 2017; World Bank 2017). The UK is committed to introducing a network of well-managed MPAs and achieving Good Environmental Status of its regional seas by 2020, and protect the economic and social benefits of these habitats (European Commission 2008; Marine Strategy Framework Directive 2008). The Marine and Coastal Access Act requires a network of Marine Conservation Zones (MCZs), a type of MPA, to manage and protect coastal marine environments in England, at the ecosystem level (Fletcher *et al.* 2014).

Currently, the UK has introduced 299 statutory MPAs, which cumulatively cover 23.6 % of UK waters (Defra 2018). Fifty MCZs have been designated in England with a further tranche of sites due for designation in 2019 (Defra 2018). Many of these MPAs are multi-use, which means they allow for certain activities to continue. These multi-use MPAs offer partial protection and typically exclude damaging activities which compromise the conservation objectives (Read 2010). Crucially, commercial fishing methods that are known to negatively impact a protected feature or habitat (e.g. trawling and / or dredging) are often managed or excluded from MPAs. Fishing practices considered to be low-impact and compatible with the conversation objectives (e.g. static methods) are typically permitted to continue. For all types of commercial fishing activity comprehensive environmental assessments are required to ensure they do not compromise any obligations to protect marine habitats, in accordance with EU directives, UK law and national legislation. Evidence-based assessments should evaluate the potential ecological impacts of different commercial fishing methods to determine their requirement for management based on the impact to designated features. Appropriate management action should be taken considering these assessments. For some multi-use MPAs (SACs, Special Protection Areas (SPAs)), evidence and understanding of the impacts and compatibility of all commercial fisheries with MPA conservation objectives have been improved through Habitat Regulation Assessments. Inshore Fisheries and Conservation Authorities (IFCAs) manage and assess marine activities that take place 0-6 nautical miles (nm) from the shoreline, and the Marine Management Organisation (MMO) manage and assess the activities taking place 6 nm to 12 nm. These assessments are based on current fishing effort, however monitoring and control plans are developed in areas where there is risk of increased fishing effort, which may lead to the deterioration of the ecosystem (e.g. Sheehan et al 2013). This research aims to help inform this process.

1.1. Fishing in the UK

Mobile commercial fishing methods such as trawling and dredging are the most common methods used in UK commercial fisheries (MMO 2015). Bottom towed fishing methods negatively impact ecosystems both directly and indirectly (Hall 1999; Jennings and Kaiser 1998). As a consequence of the impact, bottom towed fishing methods are managed within many UK MPAs to reduce the impact and degradation of sensitive habitats and species (see Association of IFCAs, 2018).

In the UK, the commercial shellfish fishery is the second largest fishery contributing to total commercial landings (weight) by UK vessels, averaging 35 % of all UK landings between 2010 and 2014 (MMO 2015). The fishery also contributes to 45 % of the total value of UK landings averaging £271 million between 2010 and 2014 (MMO 2015). Scallops (mainly *Pecten maximus*), Crabs (mainly the brown crab *Cancer pagurus*) and Norway Lobsters (*Nephrops norvegicus*) contribute to over 70 % of all shellfish landings in the UK. European lobsters (*Homarus gammarus*) are, however, economically the most valuable of all shellfish species landed (MMO 2015). Forty per cent of the total quantity of shellfish and 50 % of the total value of shellfish landed in the UK in 2014 was caught through the commercial pot fishery.

Commercial potting is termed a static fishing method (Nédélec and Prado 1990; Seafish 2015). Pots are baited and deployed to the seabed and left for a period to allow target animals to enter and be caught and then hauled. The advantages of potting allow for control over the size and species caught. Pot entrances can be altered to control the maximum size of the animals, while mesh size and escape routes can be altered to control the minimum size of the animals retained in the pot. The model or shape of the pot can be changed to target different species (Slack-Smith 2001). Pots are weighted to help maintain their position on the seabed over long time periods. Damage to the seabed and benthic communities may occur because of direct contact and also from abrasion and scour from the movement of potting gear on the seabed, particularly during periods of adverse weather and during spring tidal cycles (Eno *et al.* 2001; Lewis *et al.* 2009; Gall *In press*). Damage to sensitive habitats can also potentially occur during the setting and hauling of pots (Hartnoll 1998; Eno *et al.* 2001).

Whilst such inferences about the impact of pots on the seabed have been made, robust, quantitative empirical studies on the relationship between the intensity of potting and the resulting impact to the seabed are lacking. Consequently, commercial potting continues to be generally considered as benign, causing little overall damage to marine environments (Eno *et al*. 2001; Coleman *et al.* 2013). In Defra’s revised approach to managing European Marine Sites (EMSs), potential sources of pressure on the site are Red, Amber and Green rated (RAG rating), depending on the likely severity of impact. While generally Red-rated pressures (such as scallop dredging) are considered incompatible with the objectives of EMSs , 'static pots' are considered to pose an 'Amber' risk to 27 habitats, including: subtidal gravel and sand, subtidal mixed sediments and subtidal bedrock, boulders and cobble reefs (Defra 2013). As part of Defra's approach, this Amber rating meant that by 2016 the impacts associated with static pots needed to be assessed, with necessary management measures in place. This target was not met, and Amber risks continue to be assessed. To maintain ecosystem structure, function and fishery productivity it is vital to understand the environmental impacts associated with all commercial fishing activities.

In the UK, several technical measures are mandatory for commercial potting under European legislation, including but not limited to size limits (Minimum Conservation Reference Sizes (MCRS)) and the fitting of escape gaps in some areas, these measures are used in the Devon and Severn IFCAs district. Though, there are very few examples of effort-based management for commercial potting.

1.2. The problem?

Areas of the UK are currently exposed to increases in potting activity in inshore waters (Mangi *et al.* 2011; Newman *et al.* 2012; Cefas 2014, Öndes 2017). The number of UK vessels that class pot fishing as their primary method has been magnified by the widespread use of mechanical haulers (Munro *et al.* 1987). This technology has led to significant and increasing commercial pot landings over the past 25 years. Examples of this have been seen around the UK (Bannister 2009) including the northeast of England (Turner 2009; Cefas 2014) and in Skomer, Wales (Newman *et al.* 2012). Restrictions placed on bottom towed fishing gear have also been responsible for increases of using pots (Mangi *et al.* 2011). It is believed that this fishery could see a dramatic increase in effort, particularly in the quantity of pots used and the number of vessels fishing with pots, before the impacts of current levels are fully understood.

1.3. Lyme Bay: a case study

Lyme Bay is 2460 km^2, is located in the English Channel and the coastline covers approximately 120 km with numerous fishing ports (Rees *et al.* 2010). The area is a hot-spot with important submerged geological features encouraging a mosaic of habitats including sandstone, mudstone and limestone reefs (Black 2007) and comprising of complex mixed bedrock, stony and biogenic reefs (Black 2007; Cork *et al.* 2008; Attrill *et al.* 2011; Ross 2011; Munro and Baldock, 2012). Lyme Bay is home to a prosperous fishing industry, with numerous vessels involved in scallop dredging, trawling, netting, potting and whelk fishing (prior recent management measures) (Andrews 2008). Commercial potting has a long history in Southwest England, during which brown crab has been the dominant fishery (MMO 2015). Parlour pots, Inkwell pots, cuttlefish pots, and whelk pots are frequently used throughout the region (Stevens *et al.* 2007).

Scallop dredging was a lucrative industry in Lyme Bay but, intensive dredging removed and destroyed some of the reefs and also degraded the local geology (Devon Wildlife Trust 2007). In 2008 the UK government introduced a Statutory Instrument (SI) (a type of MPA) of 206 km^2 (60 nm^2) around Lyme Regis (Fig. 1, black line). The whole area was closed to the use of mobile fishing gear within the boundary of the SI (Defra 2008). Protection increased offshore to reduce impact to other reef areas and these additional sites were designated as a Special Area of Conservation (SAC) in 2011 under the Habitats Directive (92/43/EEC), assigning the protected area with European Marine Sites status (Fig.1, red line) (Rees *et al.* 2010; Natural England 2012). This area became part of the Lyme Bay and Torbay SAC.

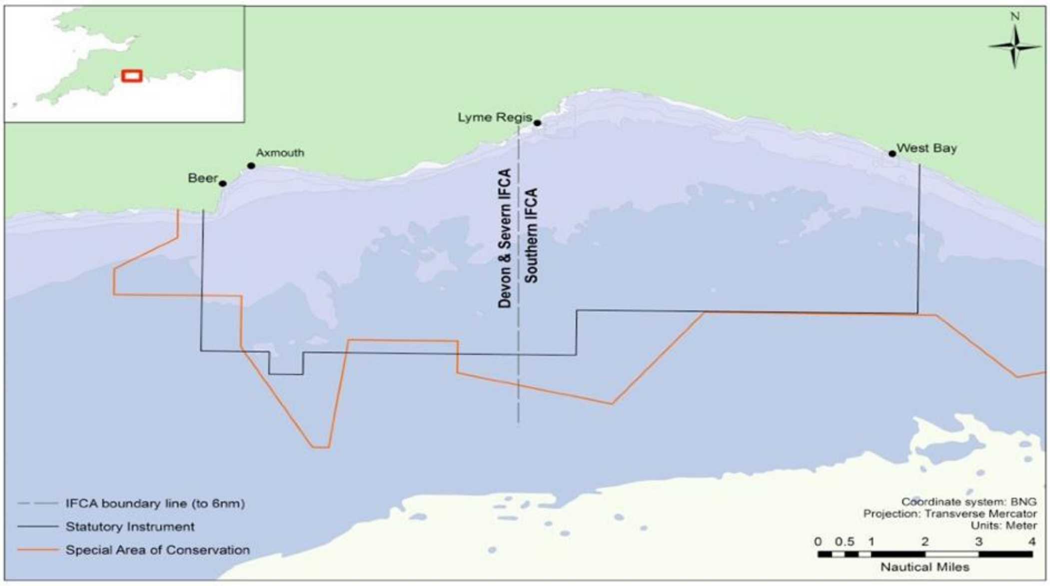

Figure 1. Lyme Bay and Torbay SAC boundaries and associated ports. Dashed line = Inshore Fisheries and Conservation Authority (IFCA) boundary line between Devon and Severn and Southern IFCA out to 6 nm highlighted.

The Lyme Bay and Torbay SAC sits on the border between two managing IFCAs, Devon & Severn to the west and Southern IFCA to the east (Fig. 1). The conservation objectives of this SAC were to '*ensure that, subject to natural change, the integrity of the site is maintained or restored as appropriate, and that the site contributes to achieving the Favourable Conservation Status of its qualifying reef features*' (Natural England 2018). These qualifying reef features included: Circalittoral rock, Infralittoral rock and Subtidal stony reef of which their extent, structure, function and supported populations should be 'maintained or restored' (Natural England 2008). The designation of the SAC led to a subsequent assessment of bottom towed fishing across the site by both Southern and Devon and Severn IFCAs. The assessment resulted in closures of bottom towed fishing across the site through the introduction of byelaws by both IFCAs. Although introduced through two separate byelaws, the ultimate management goals are the same for both sides of the Devon/Dorset border. Nonetheless, management measures for individual species caught using static gear in each of these two districts differ, for example the Minimum Conservation Reference Size of European lobster.

There are four fishing ports in Lyme Bay: Beer, Axmouth, Lyme Regis and West Bay. These ports are home to a small number of small-scale fishermen which operate within distinct home ranges to each other because of, primarily, their engine size and historical fishing grounds. While the areas they fish are viewed as distinct, fishing methods and behaviour are similar. Static forms of fishing are permitted to continue within the Lyme Bay and Torbay SAC, including potting, netting, rod and line and hand-diving for scallops plus recreational fishing activities.

To assess the efficacy of the SI, and subsequently the SAC, long-term monitoring of the recovery of the protected reefs began in 2008, led by the University of Plymouth. While also assessing the seabed assemblage as a whole, the approach focused on key indicator species that represented different functional groups following an analysis of ecological and functional traits (Jackson et al. 2008). Results have shown that several species, including key indicator species such as Pink Sea Fans *Eunicella verrucosa,* Dead Man's Fingers *Alcyonium digitatum* and King Scallop *Pecten maximus*, had a positive recovery within the SI and the SAC in comparison to those areas that continue to remain open to bottom-towed fishing (Sheehan *et al*. 2013a). After 3 years from closure, overall diversity of reef taxa had increased by 50%, while no such improvement was seen in areas still fished. Given the overall slow growing nature of many key reef-forming species, this wider study indicates that this site is still recovering and that the management of activities permitted to continue within the Lyme Bay and Torbay SAC should be routinely monitored.

Since 2008, sightings data from IFCA and Marine Management Organisation (MMO) demonstrated that the number of vessels using static gear inside the MPA is increasing. In the Lyme Bay and Torbay SAC static potting targeting crab and lobsters are the most common methods of fishing in the area. Brown crab and lobster values and landing weights have increased within the Lyme Bay and Torbay SAC, and the number of fishing trips into the Lyme Bay and Torbay SAC has significantly increased (Mangi *et al*. 2011; Vanstaen and Breen 2014; Rees *et al.* 2016). While the impact from increases in commercial potting effort targeting crab and lobster is not yet fully understood, the economic upturn of this fishery, coupled with anecdotal local fishermen reports, suggests that effort within this area could continue to increase unregulated within the Lyme Bay and Torbay SAC. An increase in commercial potting effort inside the SAC threatens the livelihoods of many local static gear fishermen (Clover *et al.* 2012).

1.4. Lyme Bay and the Blue Marine Foundation

In 2012 the Blue Marine Foundation developed a conservation proposal with the aim to achieve a 'win, win, win' outcome; for conservation, fisheries and fishing communities (Blue Marine Foundation 2012). To achieve the desired 'wins', a 'bottom-up' approach was used. A key component in this approach has been the development of the Lyme Bay Consultative Committee. This assembly includes all local fishermen from ports encompassed by the SAC, local and national stakeholders, funding bodies and policy makers. Importantly the local IFCAs and the MMO, aiming for Lyme Bay and Torbay SAC management to represent:

1. Best practice in protecting wildlife within a European Special Area of Conservation.
2. Best practice in managing fish and shellfish stocks.
3. Creating maximum long-term benefits for coastal communities by adopting best practice.

A Memorandum of Understanding was also signed by all Consultative Committee members: this is an important step in improving collaboration between fishermen, conservation bodies, scientists and marine management bodies. In return, fishermen who adopt best practice and demonstrate sustainable fishing methods should be rewarded. These initiatives are part of a wide-reaching proposal set out by the Blue Marine Foundation to meet its desired 'wins'.

The Consultative Committee initially focused on improving the management of the closed area in regard to increasing commercial potting efforts. It was decided that for the immediate future, voluntary measures should be adopted and outlined within a Lyme Bay Commercial Fishermen's Voluntary Code of Conduct. This voluntary code is an attempt to reduce the immediate impact of static gear, and to principally develop the sustainable and well-managed inshore commercial pot fishery within the Lyme Bay and Torbay SAC. The Voluntary Code of Conduct stated:

- *Fishermen will not fish more than 250 crab/lobster pots.*
- *Strings will not exceed a maximum of 10 pots in each.*
- *Escape hatches will be fitted to all parlour pots and creels, aligning the area that falls under Southern IFCAs district with that of Devon and Severn IFCA where escape hatches are already mandatory.*
- *Voluntary V-notching (Tail mutilation in female lobsters undersize or carrying eggs (berried) will be carried out at the individual fisherman's discretion.*

The impacts associated with current and increasing levels of commercial potting lacked appropriate evidence, thus a pioneering management-based project was developed by the University of Plymouth, and funded by the Blue Marine Foundation and Defra, and was designed with direct input from local fishermen.

2. The Lyme Bay Experimental Potting Study

The objective of this study was to gather evidence on the ecological impacts of potting by controlling potting effort within a number of designated areas (experimental units) in the Lyme Bay and Torbay SAC. This created a gradient of increasing potting effort from areas of no potting to areas where potting effort was considered at a maximum, and above sustainable levels of potting effort in the Lyme Bay and Torbay SAC. Data were collected over multiple years, to assess the impact of an increase in potting density on the seabed and the associated species including populations of commercially targeted species. The evidence and conclusions of this project may then be used in future evidence-based management recommendations. The study ran from 2014 to 2017.

2.1. Aims of the study

The experimental potting project assessed potting impacts on both the ecosystem and on the local fishery species. Multiple data were collected and were used to answer three different hypotheses, with aims that set out to better understand the impacts of potting on the ecosystem and local fishery.

Research studies and aims:

Ecosystem aims:

1. *Assess the impacts of increasing potting density on sessile reef species and assemblages*
2. *Assess the impacts of increasing potting density on benthic macro-mobile species and assemblages*

Fishery aims:

3. *Assess the impacts of increasing potting density on target fishery species*

A detailed description of methodologies can be found in the PhD thesis, 'The ecological effects of increasing potting density in the Lyme Bay Marine Protected Area'. A summary of methods and key results are provided here.

2.2. Outline of the study methodology

Four experimental potting treatment units were used, (1) Control (no potting), (2) Low potting density, (3) Medium potting density and (4) High potting density units were designated within the Lyme Bay and Torbay SAC (Fig. 2). Each experimental unit measured 500 m x 500 m. Units were validated through video surveys and they maintained homogenous mixed ground or rocky reef substrata between depths of 25 m – 31 m. Potting densities were maintained within each unit by static gear fishermen from each port (Beer, Axmouth, Lyme Regis, West Bay). Regular commercial potting trips were maintained within each unit by commercial fishermen representative of 'normal' levels, meaning two to three times per week during periods of stable weather, typically summer months, and one haul per week during periods of unsettled weather, typically winter months. Despite temporal variation in hauling activity, hauling was replicated within all treatments to account for variation. Experimental potting treatment units within the 500 m x 500 m areas (Fig. 2) consisted of: Control (no potting) = 0 pots, Low potting = 5-10 pots, Medium potting = 15-25 pots, and High potting = 30 pots and higher.

The densities used in the High potting treatment are considered to represent maximum fishing effort per 500 m x 500 m. Assessments of potting effort throughout Devon and Severn IFCA district in 2008 demonstrated that 36 pots per 0.25km^2 was deemed to be the maximum number of pots that can viable and economical (D&SIFCA *pers comm*.). Current levels of potting effort inside the Lyme Bay and Torbay SAC are characterised by Medium density. Low potting densities are also considered to replicate potting levels in some areas of the Lyme Bay and Torbay SAC and is a level of potting more like those pre-closure. Control units where potting was removed to simulate a 'no potting' treatment was incorporated into the study as a reference point to determine baseline changes.

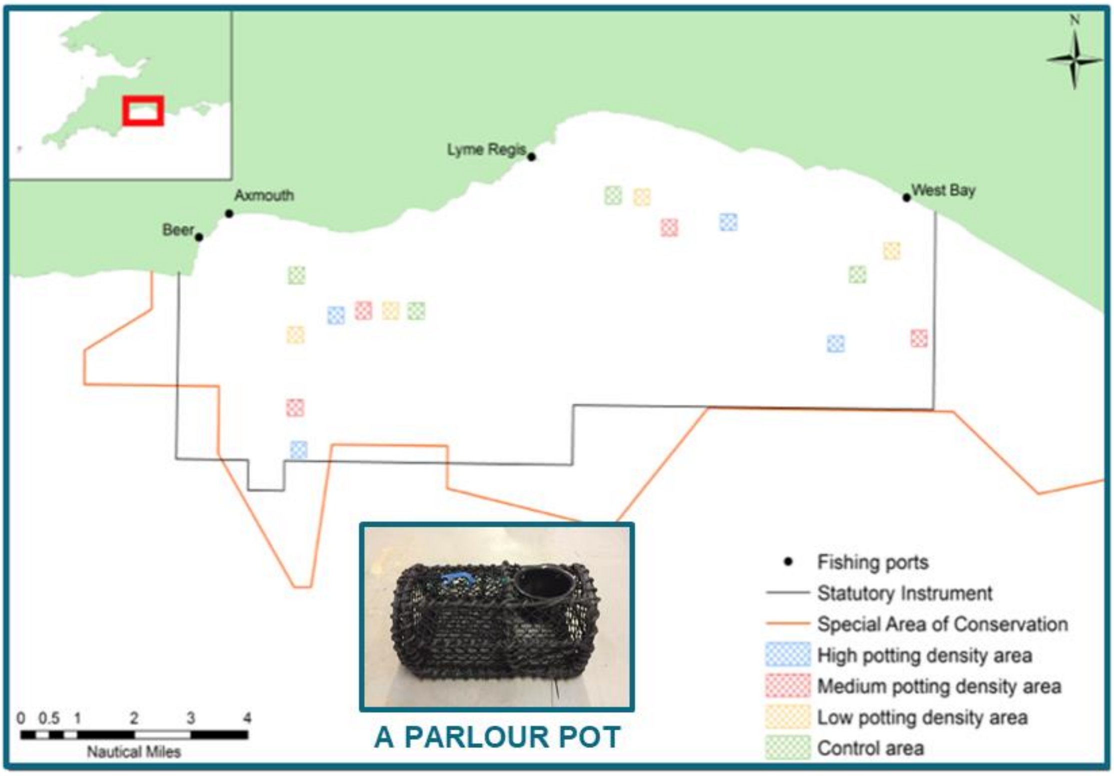

Figure 2. Distribution of experimental potting units in the Lyme Bay and Torbay SAC

To aid potting density manipulation, experimental sets of 30 experimental pots were assigned to each port to supplement density manipulation. Parlour pots were purchased from a local supplier. All pots were industry standard, measuring 70 x 52.5 x 37.5 cm. Pots had a mesh (net) size of 40 mm and each pot had a 25 cm entrance. All pots were fitted with escape gaps of 84 mm wide by 46 mm high and 100 mm long, to meet the Devon and Severn IFCA technical permit requirements for commercial potting (D&S IFCA 2011). Potting areas were spatially and temporally replicable and started from similar ecological baselines which allowed for changes over time to confidently attribute changes in potting effort.

3. Ecosystem: Study 1

Assess the impacts of increasing potting density on sessile and sedentary reef species and assemblages

3.1. Methodological summary

A towed video flying array (Fig. 3) was used to record benthic transects in each of the experimental units (Sheehan *et al*. 2010 and 2016). This is a non-destructive and cost-effective high definition (HD) video sampling technique and has been employed to assess benthic habitats in the Lyme Bay and Torbay SAC since 2008 (Sheehan *et al.* 2010 and 2016). The array was towed behind a 10 m fishing boat (Miss Pattie) at a speed of ~0.3 knots. The system includes a High Definition camera, a Surveyor-HD-J12 colour zoom titanium, 720p, positioned at an oblique angle to the seabed to maximise the field of view of the seabed. Three LED lights (Bowtech Products limited, LED-1600-13) and two green lasers positioned parallel to each other, 30 cm apart, forming a 'gate' that was used to measure and count epibiota and help quantify transect area (Sheehan *et al*. 2013a, Stevens *et al.* 2014; Fig 3). Towed video data allow for identification and quantification of benthic reef organisms, with a focus on sessile and sedentary reef species.

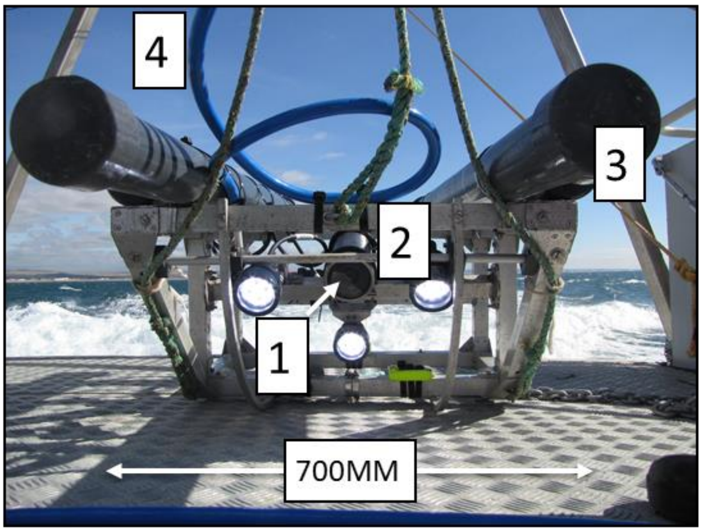

Figure 3 Towed video flying array set up and size (1 = HD camera, 2 = LED light, 3 = ballast, 4 = power umbilical; adapted from Sheehan *et al.* (2016)

Two tows were performed across the width of each experimental unit. Start points for each tow were randomly predetermined using random generation of latitudinal and longitudinal coordinate seconds. From each tow, four 50 m replicate transects (sites) were randomly selected, separated by a minimum of 100 m to avoid pseudo-replication and ensure independent replicate data. Video data analyses were conducted twice using two methodologies to quantify different organisms. Data analysis was broken down into Transect and Frame grab data. Transect data quantified large benthic organisms, infrequent mobile species and conspicuous sessile and sedentary species. Frame data quantified smaller and inconspicuous benthic organisms including encrusting species. All analyses were conducted blind with location and treatment data removed to ensure no bias was introduced. Significant results were determined only for identified species in the transect data.

Each video transect was viewed at normal speed. Transient mobile species, conspicuous sessile and sedentary species that were filmed through the 30 cm 'gate' were counted (Fig. 4). All species were

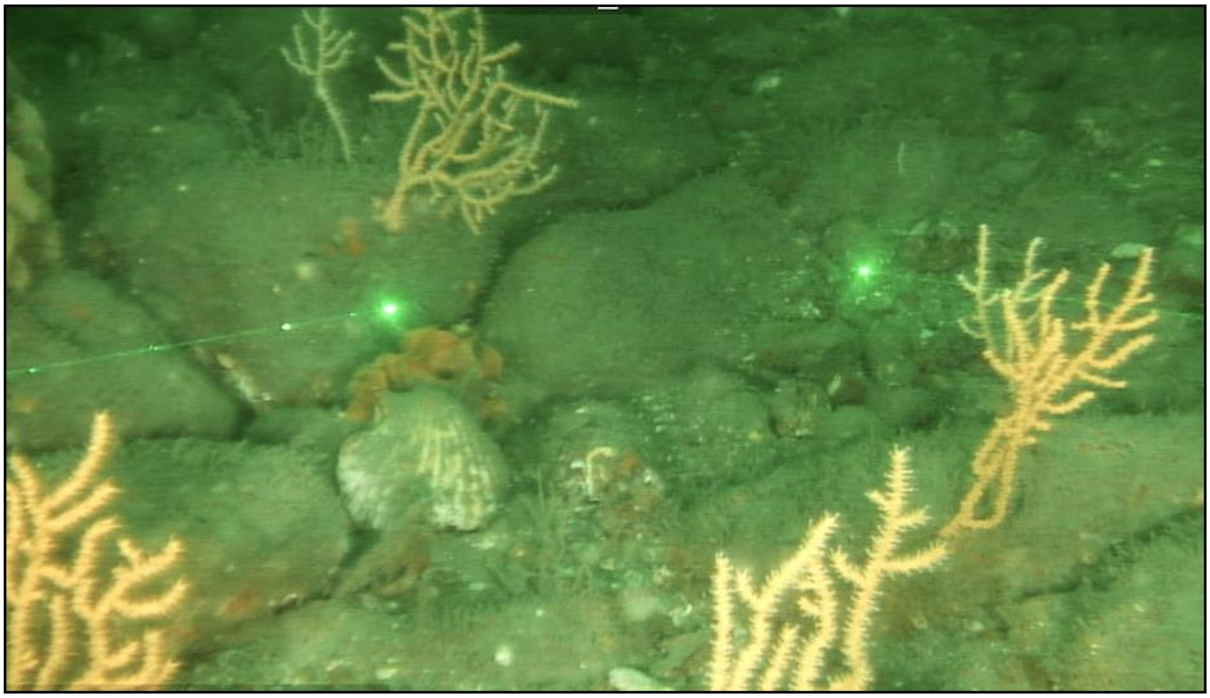

Figure 4. Screenshot from transect video showing laser 'gate' and conspicuous sessile species

identified down to the lowest taxonomic level possible. Some taxonomically similar or hard to distinguish species could not be identified down to species, so were grouped at higher taxa (e.g. branched sponges). The position of the lasers in the field of view was recorded and combined with the start and end GPS points of each 50 m tow. A laser 'gate' ensured transect area was kept consistent and allowed abundances and diversity of species to be expressed as densities per square metre (individuals per m^2, or number of species per m^2).

Subsets of species were analysed depending on their functional group; as an example, the indicator species from the sessile subset are presented below (Table 1). A predetermined indicator species list had been developed for the Lyme Bay monitoring project (see Jackson et al. 2008; Langmead et al. 2010), where representative long lived and slow growing sessile and mobile taxa were selected. These species were also considered to represent a range of life histories and recoverability in response to fishing disturbance (Jackson et al. 2008; Langmead et al. 2010). A subset of mobile species, including sedentary species (defined as slow moving but still mobile), was analysed separately to the sessile subset.

Table 1. Example indicator species for Transect analyses with associated life history and recoverability traits (Adapted from Jackson et al. 2008)

Species	Common Name	Lifespan (years)	Growth (cm/yr)	Survivability	Reproduction	Repopulation	Recoverability
Alcyonium digitatum	Dead man's fingers	>11	<1	Medium	Low	Medium	Low
Eunicella verrucosa	Pink Sea Fan	>11	<1	Low	Low	Low	Low
Pentapora foliacea	Ross coral	6-10	1-2	Low	Medium	Low	Low
Phallusia mammillata	Neptune's Heart sea squirt	3-5	3-5	Medium	Low	Low	Medium

3.2. Data analysis summary

Permutational Multivariate Analysis of Variance (PERMANOVA+ using PRIMER v7 software package) was used to test for changes in the response variables (*total abundance, species richness, assemblage composition* and *the total and individual mean abundances of indicator species*) between Control, Low, Medium and High Treatments across all Years (*2014, 2015, 2016*). An additional response variable of Functional groups (*Mobile species, Sessile species*) was analysed for Transect data only. A set of 6 indicator species was analysed separately. The indicator species list has been adapted for this study and modified based on presence/absence data of the indicator species occurring in both Transect and Frame grab analyses.

PERMANOVA is robust to datasets with many zeros and allows the testing of interactions in complex multifactorial designs with multivariate or univariate data. Multivariate data (assemblage) were square root transformed to allow rare species to contribute, while down-weighting the contribution of highly abundant species. Bray-Curtis similarity indices were calculated to construct a similarity matrix between sites. Visualisation of matrices was achieved using non-metric Multi-Dimensional Scaling (nMDS). Univariate data (total abundance, species richness and Indicator taxa abundances) were similarly $\log_{10}(x+1)$ transformed and Euclidean distance similarity matrices between sites were calculated.

Transect replicates were as assigned random factor 'site'. The analytical design had four factors: Year (fixed: 2014, 2015, 2016), Treatment (fixed: Control, Low, Medium, High), Area (random and nested in Treatment: Beer, Axmouth, Lyme Regis, West Bay) and Site (random)). Each term in the analyses used 9999 permutations of the appropriate units. Multi-level significant interactions were tested using PERMANOVA pairwise tests. P values of ≤ 0.05 were used to denote significance. Statistically significant and distinct interactions were investigated further using post-hoc pairwise comparisons in PERMANOVA+.

3.3. Key results

A total of 192 replicate transects (50 m) were collected across all study units between 2014 and 2016. Of these only 2 were unusable due to technical difficulties or poor footage: 1 replicate in 2014 and 1 replicate in 2016. A total of 40 species or species-groups were identified from seven different phyla. Figures 5 and 6 show results from the final year of collection (2016), after a three-year gradient in potting had been established, each with significance testing (for full results see Rees (2018)).

By 2016, the total abundance of sessile reef species significantly decreased in areas of high potting density after three years of density manipulation (PERMANOVA, P = ≤ 0.05 (Fig. 5; Appendix table 1)).

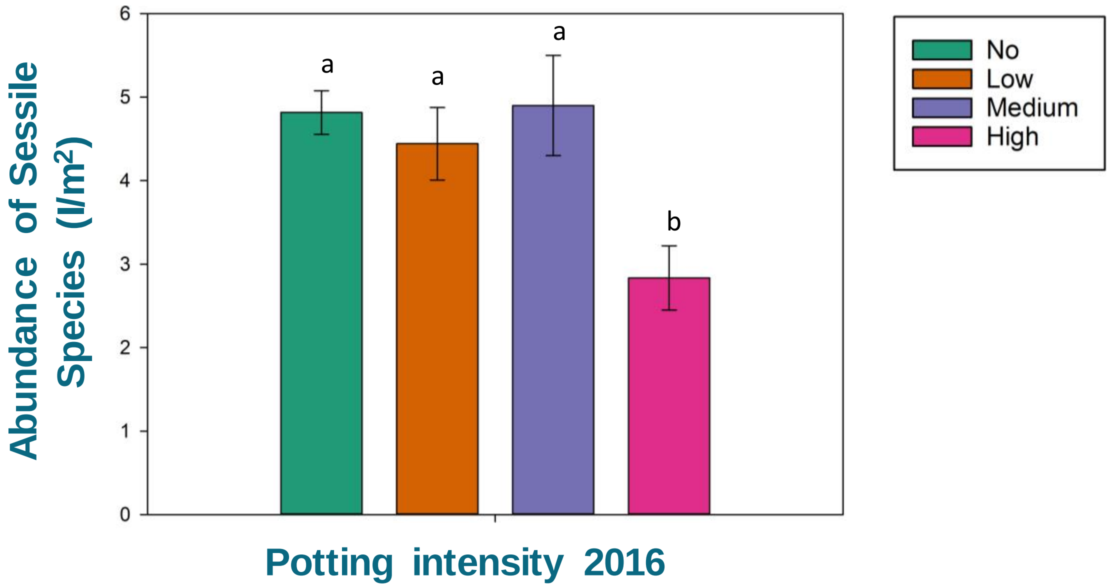

Figure 5. Total number of sessile species in each potting density area in 2016, quantified in study 1. Letters above bars = significant differences from pairwise tests (mean/m² ± SE)

Only two indicator species (see Table 1) showed any significant response to potting intensity. The Ross coral (Fig 6 a, c) and Neptune's Heart sea squirt (Fig. 6 b, d) both showed a negative response in the high potting density treatment) and are thus most likely to be the major contributors to the reduction on overall abundance displayed in Fig. 5. The Ross coral *(Pentapora folicacea)* decreased in abundance in all potted treatments (Low, Medium, High) (PERMANOVA: No pots vs Low, Medium, High, P ≤ 0.05, Fig. 6a, Appendix table 2), and the white Neptune's Heart sea squirt (*Phallusia mammillata)* showed a significant decrease in abundance in both the Medium and High treatments, but not in the low potting density areas (PERMANOVA: No pots vs Medium, High, P ≤ 0.05, Low vs Medium, High, P ≤ 0.01, Fig. 6b, Appendix table 3).

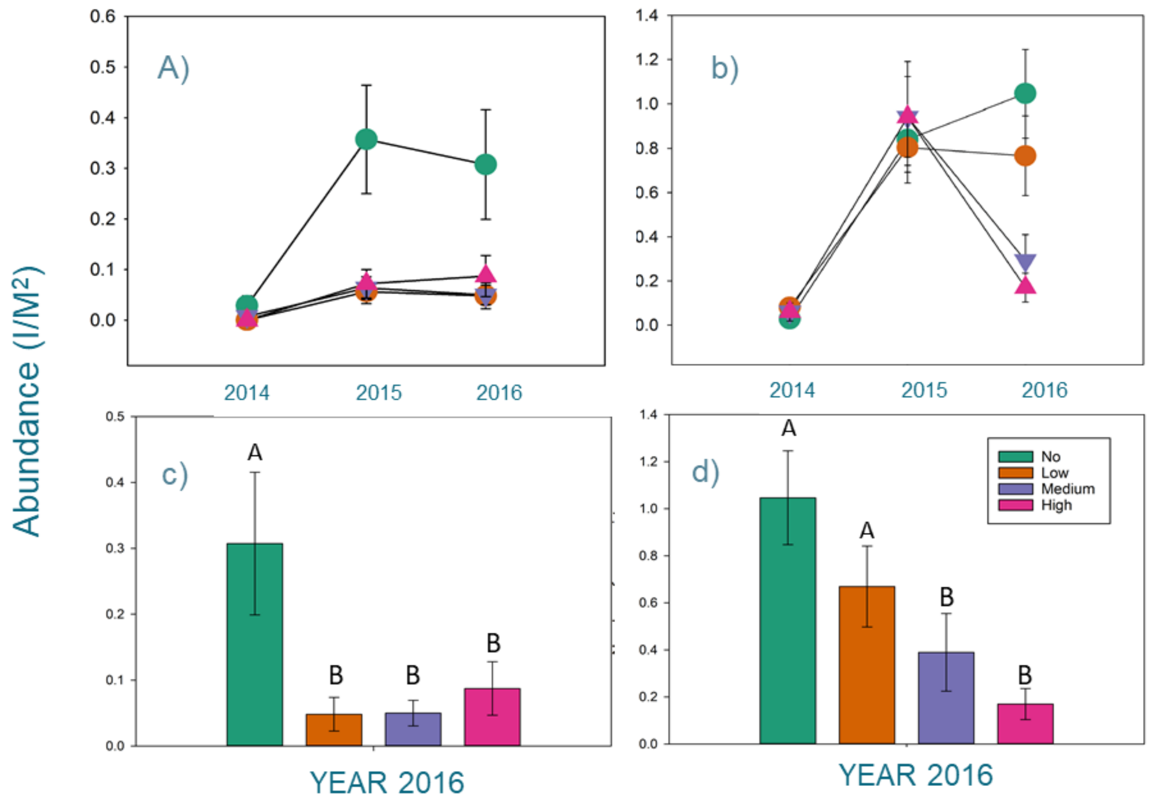

Figure 6. Total abundance of indicator species Ross Coral (A, C) and Neptune's Heart Sea Squirt (B, C) for potting density treatments from 2014-2014 (A,B) and for clarity just in 2016 after 3 years of potting pressure (C,D). Letters above bars = significant differences from pairwise test (mean/m² ± SE).

3.4. Discussion summary

The majority of indicator species studied showed no significant response to potting impact. The two impacted key species (Ross coral and Neptune's Heart Sea Squirt) are known to be detrimentally affected by bottom towed fishing, yet have to date not considered to be impacted by commercial potting, as their populations have been recovering throughout the Lyme Bay and Torbay SAC since 2008 (Sheehan *et al.* 2015). Results from this current study highlight that in a recovering system, where commercial potting is permitted, potting can potentially impact the recovery of these species. Damage associated with potting activity on *P. folicacea* (the Ross coral) has been highlighted in previous studies (Eno et al, 2001. Gall, 2016), but observations of damage were from single or short-term potting episodes. This damage has not been quantified until now and it is concluded here that over time repetitive damage from sustained potting activity on recovering populations of Ross Coral may explain the decline in abundance seen within the potted treatments (Low, Medium, High) of this study.

P. folicacea (Ross coral) is a large erect and brittle bryozoan with low recoverability, which plays an important role in the formation of biogenic reef (Cocito and Ferdeghini 2001), along with a suite of other structural species. This species forms an enveloping honeycomb structure, and is noted for being extremely slow growing, with some estimates at around 2 cm a year (MarLIN 2006; Jackson *et al.* 2008). Ross Coral is important for providing structurally complex habitat through the provision of interstitial spaces that form as part of its honeycomb. It is functionally important to the flora and fauna that use it as nursery habitat, for example juvenile fish species (Cocito and Ferdeghini 2001; Bradshaw *et al.* 2003). It also provides physical habitat which encourages the settlement of larvae and provides a structure for nest building reef fauna (Rodriguez *et al.* 1993; Pirtle *et al*. 2012). If the Ross coral is lost or removed it could impact the ecological function of reef habitat (Patzold *et al.* 1987).

Neptune's Heart sea squirt *(Phallusia mammillata)* is the largest solitary marine tunicate (sea squirt) inhabiting waters of the British Isles (Picton and Morrow 2016). It is a comparatively fast-growing suspension feeder with low fecundity that can reach around 12 cm tall and growing 3-5 cm a year (Jackson *et al.* 2008). Typically found growing on hard substratum, this tunicate has medium recoverability due to its average survivability to disturbance and high repopulation ability (Langmead *et al.* 2010). This species also provides erect structure for the settlement of larvae, provides a nursery for juvenile mobile species and laying of eggs or nests; much like the functional role that *P. folicacea* (Ross coral) occupies. The cellulose test of the Neptune's Heart sea squirt *(P. mammillata)* is tough, but the weight and tension of pots and their ropes would be enough to remove this species; as noted by Eno *et al.* (2001), 'evidence of some detachment of ascidians and sponges', similar to the removal of sea whips (Hall *et al.* 2008) or sea fans (Eno *et al*. 1996, 2001) has also been observed.

Some trends were noted in terms of the response of other indicator species; while these were not significant they are worthy of note as may indicate a longer-term response that the current time frame has not completely documented. For example, during the study, populations of *E. verrucosa* (Pink Sea Fan) and *A. digitatum* (Dead Man's Fingers) slightly decreased in abundance in both Medium and High potting treatments, while abundance stayed the same or increased in the lower density potting treatments. These species have been observed growing on sediment with underlying hard substratum (Sheehan *et al.* 2013b), and this attachment potentially reduces the threat of being removed from the seabed (Newman *et al.* 2012) despite their survivability being considered as low (Jackson *et al.* 2008). Overall, however, the results suggest that susceptibility to potting impacts of the majority of species studied is low.

The two impacted species form part of the associated Annex I reef communities of reef habitats in the Lyme Bay and Torbay SAC, and are classified as indicators for recovery in response to the exclusion of bottom towed fishing (Sheehan *et al.* 2013a). These results should be considered in the context of the conservation objectives of the Lyme Bay and Torbay SAC. The objectives state that the extent, structure and function of the reef species assemblage should be maintained or restored. The results from this project can provide fisheries managers with information to assess the sustainability of this fishery when assessing the conservation objectives of the Lyme Bay and Torbay SAC.

This study is the first of its kind, quantifying the impact of commercial potting on sessile reef habitats over multiple years. We have demonstrated evidence of the first known ecological impacts associated with commercial potting, but that is dependent on the intensity of the potting activity.

4. Ecosystem: Study 2

Assess the impacts of increasing potting density on benthic macro-mobile species and assemblages

4.1. Methodological summary

The methods used in Study 1 are considered unsuitable for quantifying benthic macro-mobile faunal species and assemblages. Many benthic macro-mobile species may occupy waters just above the benthos which are missed by towed underwater video, plus shy mobile species often take refuge under rocks and would therefore be missed. In order to representatively sample benthic macro-mobile species, a Baited Remote Underwater Video (BRUV, Fig. 7) approach was chosen. BRUV rigs were used to record HD video samples. This technique has been used to quantify macro-mobile species and assemblages (easily visible and identifiable from BRUV) in previous studies in Lyme Bay (Attrill *et al.* 2011; Sheehan, E. V. 2017 Unpublished data). BRUV rigs were deployed by both Miss Pattie (fishing vessel) and Blue Turtle (charter dive vessel),

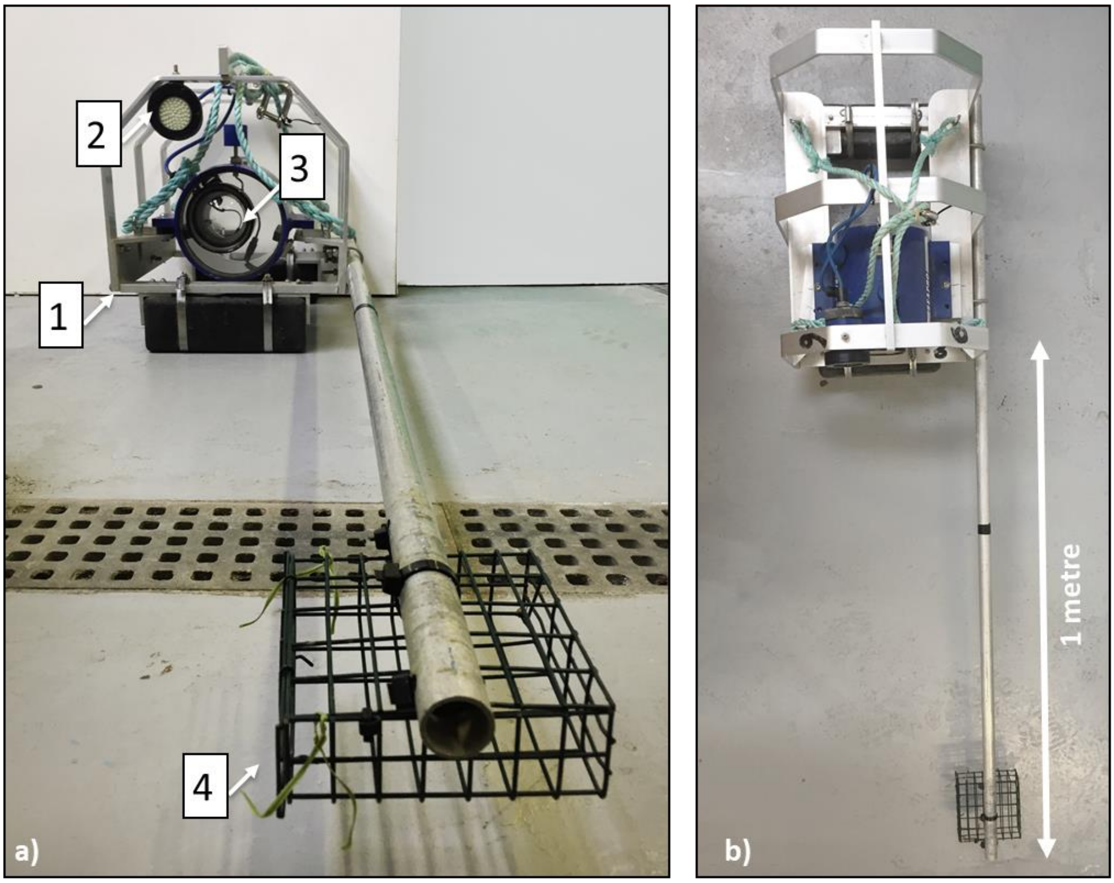

Figure 7. a) BRUV rig set up (1 = Rig frame, 2 = LED light, 3 = camera module housing, 4 = bait box attached to bait pole b) top view of BRUV rig set up, with bait pole dimensions

based out of the port of Lyme Regis. Each rig was attached to numbered surface marker buoys indicating replicate number.

Each BRUV rig (Fig. 7) was constructed of aluminium composite, equipped with a single Seapro wide-angle 50-watt diffused LED light. Seapro Subsea Video Camera Modules with a depth rating of 100 m were wing mounted in the centre of each frame housing a Panasonic HDC-SD60 Full HD Video Camera. Cameras auto focused through a Wideangle Seapro Optolite Port lens which had a concave inner surface and flat front, providing a wider field of view. This allowed a sharp focal, from a few mm in front of the port to infinity, providing suitable optical flexibility for measuring mobile organisms. A pole measuring 1 m held a wire mesh bait box placed in the cameras field of view (Fig. 7). Bait boxes contained 100 g of fresh cut mackerel as bait and this was renewed for each replicate.

Two sites were randomly predetermined within each experimental area and at each site three replicate BRUV rigs were deployed simultaneously. Deployed BRUV rigs were left static on the seabed for a minimum of 35 minutes. A 35 minute 'soak' time was considered suitable to allow a standardised 5 minute 'settling' period and a 30-minute video sample to be extracted. Thirty minutes was decided based on species accumulation curves analysed as part of previous baited video work in Lyme Bay (Sheehan et al. in prep). These timings provided time for disturbed sediment to settle and an olfactory trail to be established. Site depths and sea surface temperatures varied from 25.4 m - 28 m and 14°C - 18.4°C. This was repeated for each of the 16 experimental units in a randomised fashion, carried out over 3 days.

Analysis was visually conducted *post hoc* using a computer, and BRUV samples were used to identify and quantify all benthic macro-mobile fauna. From each 30-minute sample quantitative data were extracted using normal speed playback, which all macro-mobile species entering the field of view were recorded (Fig. 8). Counts were performed for each one-minute segment of video (maxN), to ensure that recorded individuals seen multiple times within frames were not double-counted (Willis and Anderson 2003). One-minute counts were then averaged over the 30-minute period to provide a mean maxN. Analysis was undertaken blind as videos were selected for analysis at random with no indication of video location, site or treatment. These methods were adapted from existing baited video assessments previously undertaken in Lyme Bay (Sheehan *et al.* 2013a,b; Stevens *et al.* 2014; Sheehan *et al.* In prep). Species were identified to the lowest taxonomic rank possible.

An indicator species subset was analysed to provide further insight into potting impacts on benthic macro-mobile species.

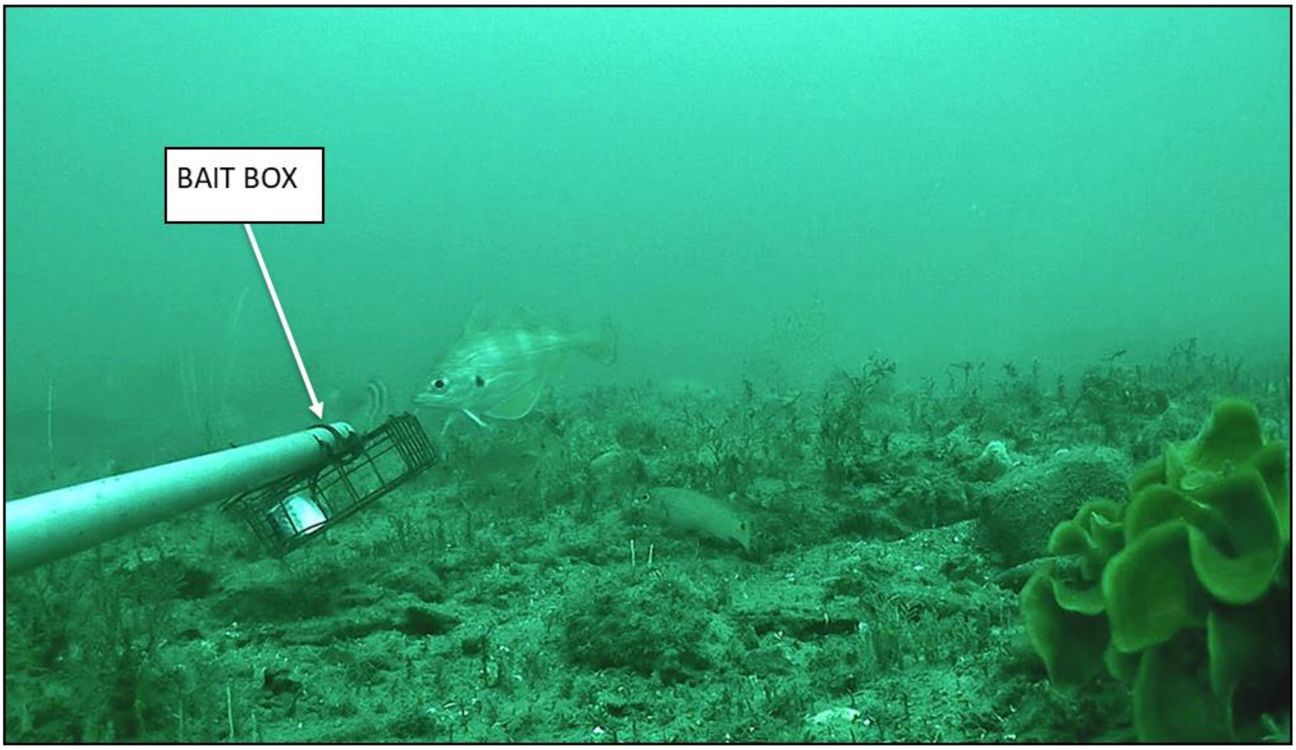

Figure 8. Example of BRUV sample video still image field of view with bait box (Year: 2016)

4.2. Data analysis summary

Data analysis and parameters were set like those described in section 3.2 of this report. Permutational Multivariate Analysis of Variance (PERMANOVA+ using PRIMER v7 software package) was used to test for changes in the response variables (*total abundance, species richness*, *assemblage composition* and *pot caught species).* Individual mean abundances and assemblage composition of *indicator species* were also tested. All response variables were tested between Treatments (Control, Low, Medium and High) across all Years (2014, 2015, 2016). Analyses of response variables were tested using BRUV data. BRUV data used six indicator species; Ballan wrasse (*Labrus bergylta*), velvet swimming crab (*Necora puber)*, the common starfish (*Asterias rubens*), pollack (*Pollachius pollachius*), Poor cod (*Trisopterus minutus*) and the Lesser Spotted dogfish (*Scyliorhinus canicula).*

4.3. Results summary

No significant treatment effect was noted for any measures investigated relating to the mobile species, suggesting that, in this experiment, potting did not have a demonstrable impact on this part of the fauna. In detail, significant differences in abundance between Year (PERMANOVA, $P \leq 0.01$) were found but there was no observed significant Year x Treatment interaction ($P \geq 0.05$ Appendix table 4a). For species richness significant differences between Year were found ($P \leq 0.001$), but no significant Year x Treatment interaction ($P \leq 0.01$) Appendix table 4b).

Assemblage composition also differed among years (PERMANOVA, P ≤ 0.001) (Appendix table 4c), but as there was no Year x Treatment interaction (P ≥ 0.05, Appendix table 4c), the assemblages were not altered by fishing pressure above and beyond this year-on-year variation.

4.4. Discussion

There is no evidence from this study that potting impacts the mobile species investigated. As there was some notable impact on the sessile structural fauna, particularly at high potting densities, this result could be interpreted as a lag between the impact on the sessile benthic habitat and the detection of consequent impacts on associated mobile species and communities. It is, however, also possible that the extent of impact from elevated potting density on sessile benthic species is not enough to negatively impact associated mobile species. Mobile species would regularly range beyond the boundaries of the treatment units, which are small in scale, so any observed changes to the habitat might not be substantial enough to either build up mobile biomass within the area or, conversely, to dissuade species from entering impacted areas. It is noteworthy that the data collected here represents the first example of an assessment of the responses of reef associated mobile species to increases in commercial potting activity.

5. Fishery: Study 3

Assess the impacts of increasing potting density on target fishery species

5.1. Methodological summary

The behaviours of brown crab (*Cancer pagurus*) and the European lobster (*Homarus gammarus*) make them inconspicuous in rocky reef habitats, and so the video survey techniques used in Studies 1 and 2 were unsuitable to collect necessary data for fisheries assessment. Quantitative pot sampling was undertaken in each experimental area. To account for seasonal variation, sampling occurred every three months: Spring (March), Summer (June), Autumn (September) and Winter (December/January), across all years (2014, 2015, 2016). Thirty experimental pots (same pots used for density manipulation), divided into six strings of five pots, were baited and randomly deployed throughout each experimental unit. To representatively sample the entire crab and lobster population, escape gaps were closed for sampling, with dispensation from Devon & Severn IFCA.

Frozen Scad, *Trachurus trachurus*, was used for bait on account of its suitability to current commercial potting practices, low economic cost and annual availability. Pots were left to 'soak' for a 24-hour period (Min 21-h, Max 30-h, mean ± SE 1.9 h). Catch from each string was sorted into species and kept for further analysis, while species that would not survive for long out of water were counted and returned. For the brown crab and lobster abundance, carapace widths and carapace lengths (mm) were measured (See Fig. 9). This measurement methodology is consistent with industry standards for these species. Wet weight in grams using a 10 g - 40 kg digital hanging scales were used. After sampling, all species were returned to within the treatment area from where they were collected. Sampling was repeated quarterly for all treatments and across all ports.

5.2. Data analysis summary

Using the quantitative potting data, abundance response variables (for all individuals and those under Minimum Conservation Reference Size) plus morphometric response variables for size (Carapace width (CW) for Brown Crab/Carapace length (CL) for Lobster; Fig. 9*)* and weight were compared using PERMANOVA between factors Area, Treatment and Year, with replicate strings assigned a random factor.

To examine the relationship between size and weight, and to quantify any changes in condition between Treatments within each Year (pooled by Season in each case to account for seasonal variability), intraspecific allometric comparisons were used. Carapace width/length and weight have previously been shown to be highly allometric in ecological studies (Peters 1983), and studies of Crustacea ontogeny (Hartnoll 1974). Demographics; <MCRS, Adult Males and Adult Females were separated to account for likely ontogenetic differences in growth rates. To compare allometric morphometric (Size x Weight) relationships, data were first log(ln) transformed so coefficients of determination (r^2) could be compared using linear regression, calculated using R 1.0.153. Coefficients of allometry were then calculated (Hartnoll 1978; Farías-Tafolla 2015; Klingenberg 1996, 2016). Relationships were described using the allometric equation $y = \beta X a$ (where y = W, β = Y intercept and X = L and a = a regression coefficient, in this case relative change in W per unit of L) (Hartnoll 1978).

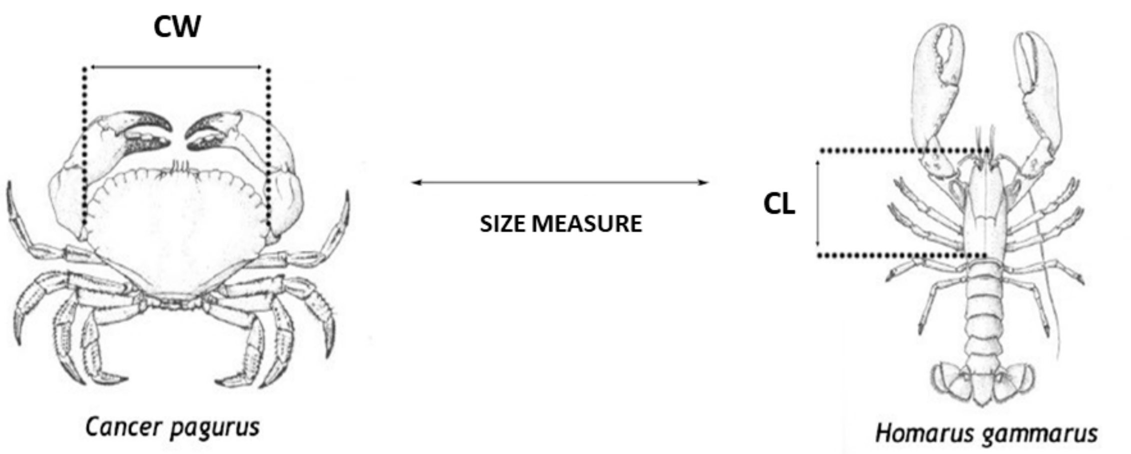

Figure 9. Size measurements (Brown Crab, *Cancer pagurus* = carapace width (CW), and Lobster, *Homarus gammarus* = carapace length (CL)) for target species caught during quantitative potting (images, not to scale, adapted from Hayward and Ryland, 1995).

As this equation is being applied to log data it is rearranged to:

Equation A: $\log y = \log \beta + a \log X$

The log linear model was tested using Pearson's chi-squared goodness of fit test which showed the model was a significant predictor (X^2 (2, N = 1038) = 0.89, p ≥ 0.01; Appendix table 7) comparing expected values to observed values in the width-length relationship. This was validated by visually analysing the residual plot which showed a normal distribution of errors suggesting the model was correct on average for the fitted values. For regression comparison allometric growth coefficients *α* and *β* were compared, where *α* describes the slope of the regression and the strength of the relationship and *β* describes the intercept. This allowed assessment of any changes to individual brown crab and lobster weight change at a given size across treatments. Coefficients were calculated from the linear regression outputs. Growth coefficients were normalised and then compared against Control Treatment coefficients (C *v* L, M, H) within each Year (1, 2, 3), for all demographics (<MCRS, Adult Males and Adult Females) ANOVA and pairwise comparisons were carried out where necessary, using the statistical software IBM SPSS Statistics 22. Coefficient data were visualised using a nMulti Dimensional Scaling (nMDS) ordination plot using the PRIMER v7 software package. Condition analyses were performed for both brown crabs and lobsters. Due to small sample sizes of some demographics for lobsters, relationships were not tested between demographics.

Multivariate and univariate analyses were performed using Permutational Multivariate Analysis of Variance (PERMANOVA), with PERMANOVA+ in the PRIMER v7 software package (Anderson 2001). Analyses used a three-factorial design consisting of Year (Year 1 (2014/15), Year 2 (2015/16), Year 3 (2016/17)), Treatment (Control, Low, Medium, High) and Area (Beer, Axmouth, Lyme Regis, West Bay). Each term used 9999 permutations of each reduced model (Anderson & ter Braak, 2003). Values of ≤ 0.05 were used to denote significant differences in the data testing, with significance then investigated further using *post-hoc* pairwise comparisons in PERMANOVA+.

5.3. Key results

A total of 7390 brown crabs (N = 6696) and lobsters (N = 694) were sampled. 149 brown crabs (2.2%) and three lobsters (0.4%) were damaged with one or two chelae missing. Fifteen brown crab had two chelae missing. All damaged individuals were excluded from weight and condition analyses because of misrepresentative wet weights. There were no dead individuals recorded during the sampling.

The research demonstrated that after three years of high density potting, impacts were found on the target species. For brown crab a significant decline of 20% (P ≤ 0.05, Appendix table 5a) in the mean number of crabs caught (per 30 pots) was observed in areas of high potting density (Fig.10a). A similar significant decline (12%, P ≤ 0.05, Appendix table 5c) was seen in lobster (Fig.10b).

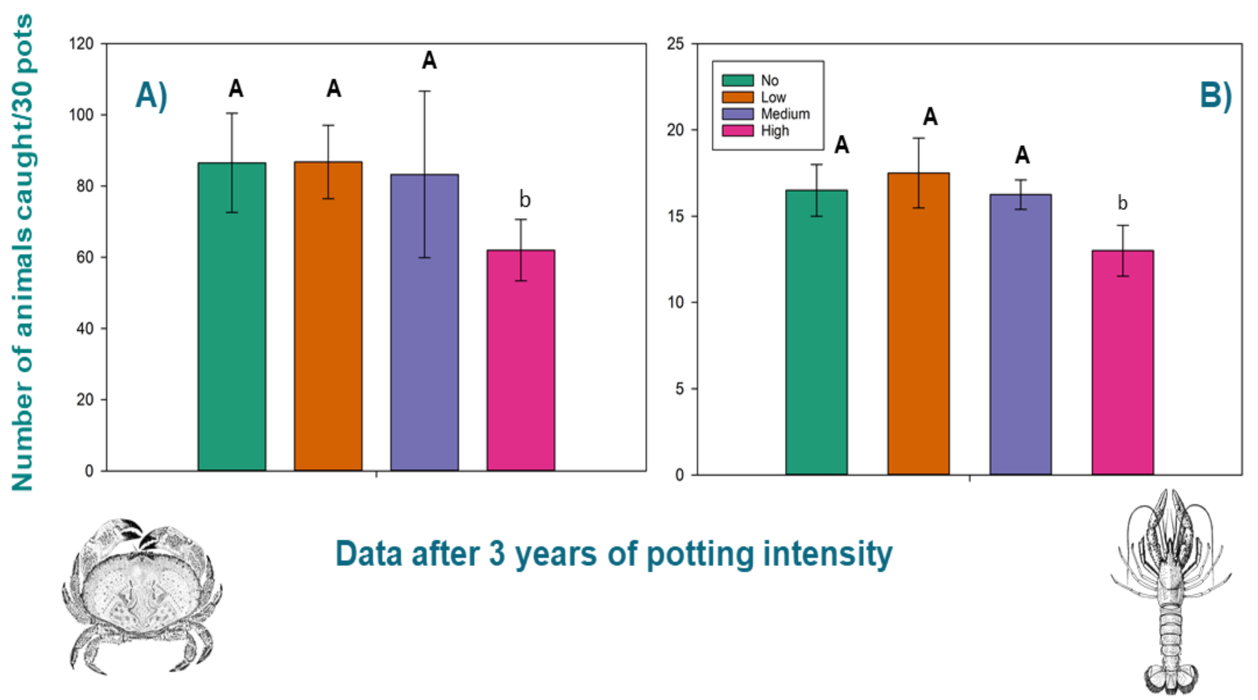

Figure 10. Number of (a) brown crab and (b) lobster caught per 30 pots in each potting density area in 2016. Letters above bars = denote significant differences from pairwise test (mean ± SE).

As expected, all width x weight relationships for all demographics of *C. pagurus* (brown crabs) were significantly correlated (P ≤ 0.001, Table 1.2 (r^2 column); Table 2; Appendix table 7). Allometric growth coefficients from log linear regressions varied between -4.521 (Year 3, High, <MCRS) and -1.849 (Year 2, Low, Adult Males) for *a*, and 2.149 (Year 2, High, Adult Males) and 3.120 for *β* (Year 3, Medium, <MCRS) (Table 2). Only results from Year 3 have been tabulated, for full table see Appendix table 7. For *a* allometric growth coefficient comparisons, four demographics differed significantly (P ≤ 0.05) to Control treatments of that year, Year 2 (Medium, Adult Females; Appendix table 7) and Year 3 (Medium = Adult Males, Adult Females, High = Adult Males; Table 2). For the *β* coefficient there were no significant deviations by any demographic for all treatments and years tested (Table 2; Appendix table 7).

TABLE 2. Condition growth equations (*y*=) and linear relationships (r^2) for all treatments in year 3 for *C. Pagurus* (brown crabs). ANOVA results testing allometric growth coefficients of control treatment. Asterisk level denotes significance level

			Linear regression		Anova *a* significant ≠ control	Anova *β* significant ≠ control
Treatment	**Demographic**	**n**	**Allometric growth equation**	r^2	**P =**	**P =**
Control	<MCRS	365	$y = -4.156x + 3.183$	0.808***	No test	No test
	Adult Males	100	$y = -2.364x + 2.351$	0.882***	No test	No test
	Adult Females	144	$y = -2.978x + 2.495$	0.882***	No test	No test
Low	<MCRS	369	$y = -4.020x + 3.130$	0.847***	0.19	0.47
	Adult Males	88	$y = -1.941x + 2.160$	0.859***		
	Adult Females	126	$y = -2.886x + 2.323$	0.795***	0.2811	0.577
Medium	<MCRS	428	$y = -4.246x + 3.210$	0.850***	0.274	0.914
	Adult Males	61	$y = -4.282x + 2.614$	0.683***	0.0279*	0.6239
	Adult Females	113	$y = -3.248 + 2.836$	0.918***	0.0273*	0.7971
High	<MCRS	257	$y = -4.521x + 2.697$	0.739***	0.294	0.512
	Adult Males	107	$y = -4.222x + 2.426$	0.882***	0.0271*	0.7471
	Adult Females	117	$y = -3.492x + 2.502$	0.917***	0.0540	0.746

Figure 11 shows the *a* allometric growth coefficients for demographics in a nMDS plot, across all treatments and Years. Four large distinct groupings of based on similarity of coefficients, and one isolated grouping (High, Year 3). Grouping C highlights the significant differences of Medium and High treatments compared to Low and Control treatments (Grouping A) in Year 3 in particular (Fig. 11).

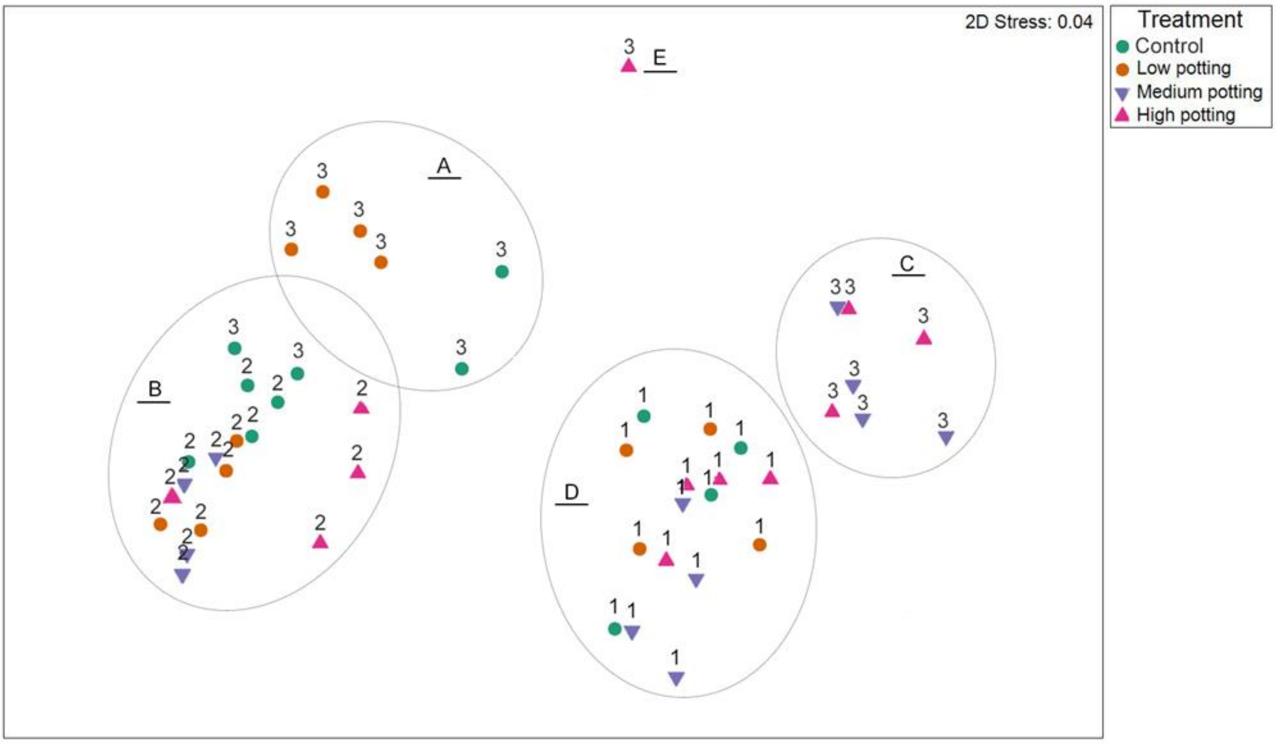

FIGURE 11. NMDs ordination plot illustrating *a* allometric growth coefficient similarities for all treatments (control, low, medium, high) and years (1,2,3) for *C.pagurus* (brown crab) adult male and female demographics. Dotted line envelopes denote groupings at a similarity level of 10% (A,B,C,D,E). Note separation of medium and high potting from low and control by year 3.

Log linear width x weight relationships for the *C. pagurus* (brown crab) Adult Males demographic from all treatments in Year 3 have been graphed for comparisons. Allometric growth equations and width x weight log relationship lines have been plotted, treatments which differed significantly in their allometric growth coefficients to the Control potting coefficients in Year 3 have been indicated (Fig. 12; Table 2).

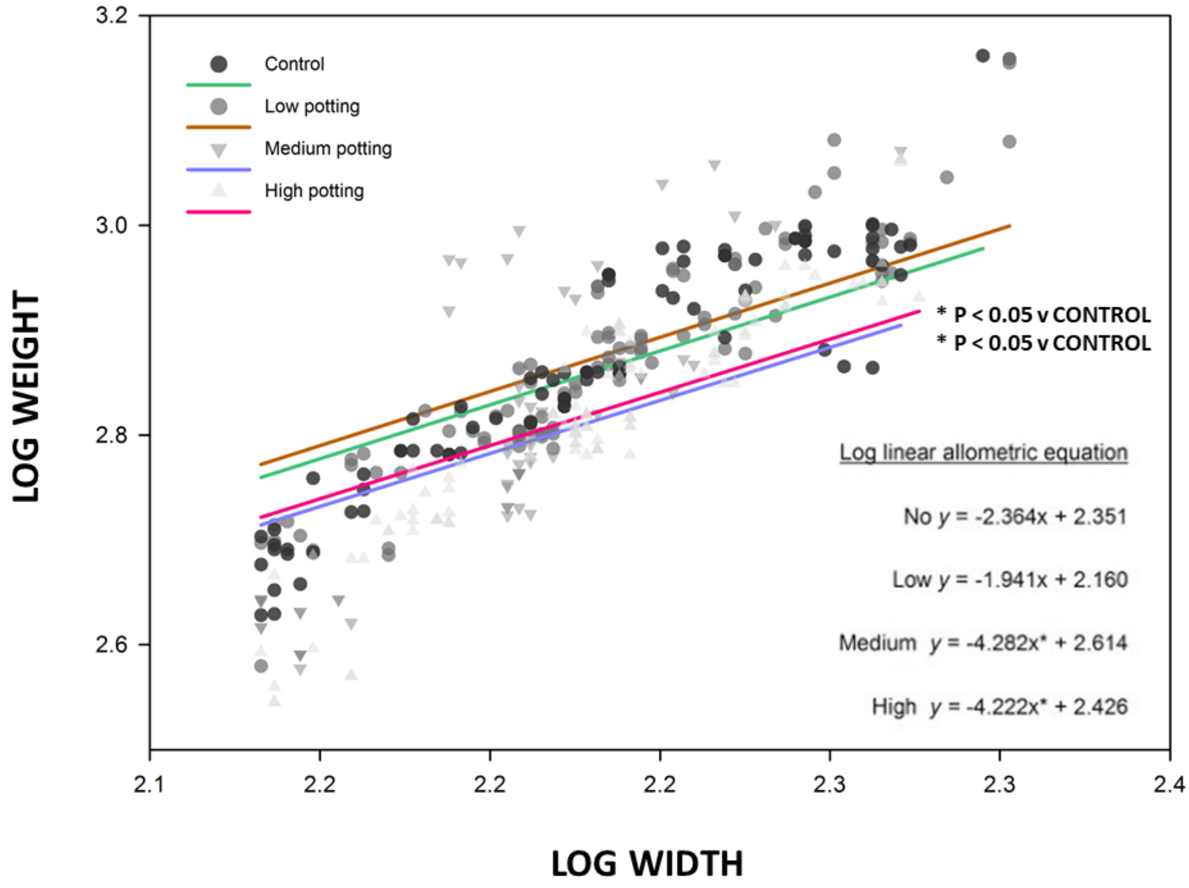

Figure 12. Log-linear width x weight relationships (plus all plotted data, black and white symbols) for *C. pagurus* (Brown Crab) adult males demographic for all treatments in year 3. Significant differences (to control treatment) in *a* (intercept) coefficients are shown with asterisks (table 2).

In addition, univariate PERMANOVA testing showed mean individual brown crab weights in Medium and High potting areas were significantly lower (Medium P ≤ 0.001, High P ≤ 0.05) than in Low potting density and in no potting areas, after three years (Fig. 13b, Appendix table 6b,c). This is a decline of 9% (≈ 50 grams) in weight on mean individual crab. Again, only results from adult brown crab (male) results from year 3 have been graphed here.

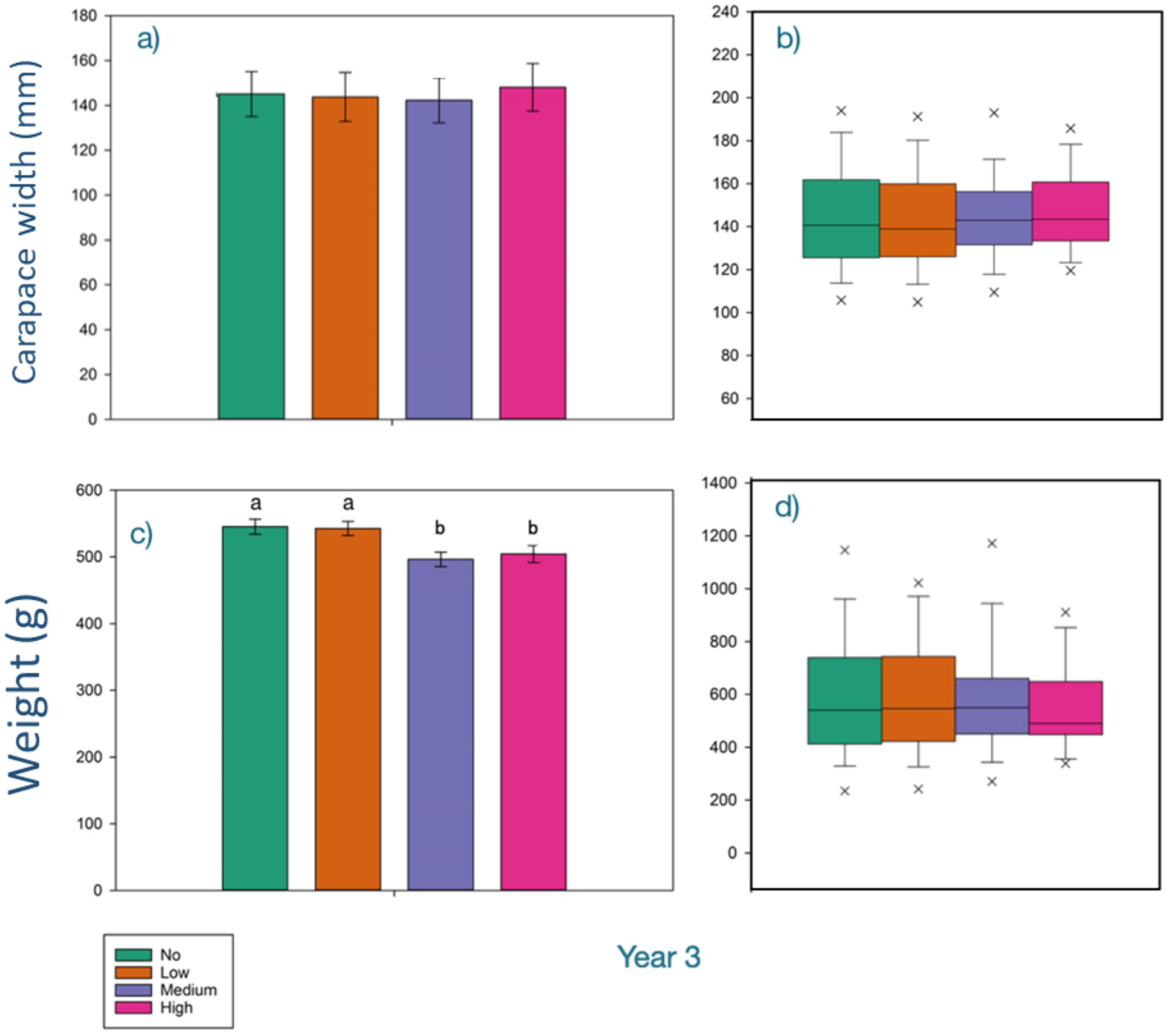

Figure 13. Mean individual a) carapace width (size) of *C.pagurus* (brown crab) - letters above bars denote significant differences from pairwise tests = mean ± SE) and b) frequency distribution box plot for carapace width for *C.pagurus* (brown crab) (box plots denote 50% of total frequency distribution with horizontal lines representing the median for each. Above median line = quartile 3 (Q3) and below = quartile 1 (Q1). Tails show 5th to the 95th percentile of the frequency distribution of the data and X locates furthest outliers outside these percentiles. Figures c) and d) show weight of *C.pagurus* (brown crab). All figures show results from each treatment for year 3 of the study.

5.4. Discussion summary

The results demonstrate that Brown crab being caught in areas exposed to a Medium and High level of potting on average weigh less than those from low and control treatments; condition of brown crab in these areas therefore has decreased over time. These impacts may be due to a selective fishing pressure being placed on adult brown crabs driven by an economic incentive for commercial fishermen to select for heavier individuals of legally-sized brown crabs, on account of their increased meat content leading to greater economic return at market (MMO 2015). The ecological consequences of this shift in overall condition are not known, however weight can be considered a proxy for muscle quality because of blood protein content which increases with muscle content (ICES SGCRAB Report 2004). The energetic demands of growth and reproduction in brown crabs are reliant on internal body composition. A reduction in mean individual weight, and thus condition, among the brown crab population of highly potted areas could potentially impact the ecological processes of this species, including reproductive success and productivity but this is yet to be proven (Levitan 1991).

Impacts on the mean number of brown crabs caught during experimental sampling were seen in the areas exposed to commercial potting effort **above** current levels. It is important to consider these results in the context of the study, which artificially increased potting to a level beyond that of current levels in the Lyme Bay and Torbay SAC. Such increases represented a spatial maximum of potting effort (density of pots per 500 m x 500 m area). A decline in the *condition* of brown crabs was observed in areas exposed to both **current** levels and **above** current levels of commercial potting in the Lyme Bay and Torbay SAC, sustained over three years. While this may not be representative of typical commercial potting behaviours in the Lyme Bay and Torbay SAC, it does highlight potential impacts of potting effort if potting density and duration is high. If commercial potting can reach high levels for comparable lengths of time to this study then brown crab quality, and subsequently economic return for fishers, may decline over time. There was no observed impact on the quality of European lobster caught during the study, but the number caught also declined in areas of high potting, again above current levels of potting in the Lyme Bay and Torbay SAC.

6. Synthesis

This collaborative study has successfully controlled commercial potting effort within experimental areas and exposed areas of protected rocky reef habitat to a sustained gradient of increasing potting density inside the Lyme Bay and Torbay SAC. This gradient included areas where potting was removed, areas that represented current levels of potting in the Lyme Bay and Torbay SAC (Medium) and areas where potting effort was experimentally increased (High) to replicate a scenario that demonstrated the highest level of potting (density of pots per unit area) possible. Impacts of increasing potting effort on both the *ecosystem* (Study 1,2) and *fisheries* (Study 3) were both assessed in order to test the efficacy of the Lyme Bay and Torbay SAC in providing benefits to both. This research was part of a collaborative project funded by the Defra and commissioned by the Blue Marine Foundation, the results of which can now be taken forward to inform appropriate management. This study demonstrates the first quantitative assessment of the ecological impacts associated with increasing potting density, over a duration of three years. A summary of findings is presented below:

Ecosystem impacts summary

- Potting areas were environmentally, spatially and temporally replicable and started from similar ecological baselines with suitable control sites, from which changes over time could be confidently attributed to changes in potting density. The site itself is currently a recovering system; recovering from trawling (since 2008) and severe storms (winter 2013/2014).

- The number of sessile reef individuals decreased over time within the High potting density areas - with significant differences in abundance being observed in 2016.
- High potting density areas represent densities higher than current levels in the Lyme Bay and Torbay SAC.
- Potting impacts were seen in two key indicator species: the Ross coral *P. folicacea* and the Neptune's Heart sea squirt *P. mammillata.*
- The indicator species *P. folicacea (*Ross coral) was approximately 80% higher (mean abundance) in areas of No potting compared to the potted treatments in 2016, while *P. mammillata (*Neptune's Heart sea squirt) was observed to be approximately 25% lower (mean abundance) in medium and high potting treatment in 2016.
- For *P. folicacea (*Ross coral*),* there were observed impacts from low level of potting. This was the only time an impact of low potting was observed across all the studies. This species is recovering from being removed from the ecosystem entirely during the severe storms of winter 2013/2014 (Sheehan et al. In press) and are in very low abundances. In the context of this study the order of magnitude of detection of this species is at its lowest (single occurrences), which should be taken into account when considering impact.
- Results demonstrate a threshold (density of pots) at which potting impacts begin to be detected for some of the indicator species tested. This was the first experimental test looking at the cumulative potting impacts on a rocky reef habitat over multiple years. Results should always be considered in the context of this experimental set up but have demonstrated that potting can cause ecological impacts to highly sensitive species.
- In practice, potting efforts and behaviours in the Lyme Bay and Torbay SAC are spatially variable. Potting fisheries typically follow the seasonal movement of lobster and crab; areas of habitat will therefore be exposed to different potting levels throughout the year as target fishery populations move, often during times of spawning.
- Reef associated mobile species did not show any detectable responses different potting densities.

Fishery impacts summary

- Over time the mean number of brown crabs caught in areas of Medium and High potting density declined by almost 20% in comparison to areas of low potting and areas where commercial potting has been removed.

- Mean individual weight of brown crabs also declined in Medium and High potting density areas, while carapace widths remained consistent and similar between potting densities.
- Overall condition of brown crab was therefore shown to decline in response to increasing potting density.
- For European lobster, the number caught declined by around 12% in the High potting density area in comparison to the lower potting density areas, in the last year of the project.
- Mean individual lobster mean weight and mean carapace lengths were not observed to change in response to different potting densities, so it is concluded that the condition of lobsters is not impacted by increasing potting density.
- Results were observed in areas exposed to sustained and spatially restricted potting activity

6.1. Limitations

The experimental design of this study allows for the control of multiple variables in order to robustly test the effects of increasing potting. However, some variables remain out of control in the context of this study (activities of part-time or recreational fishermen). While reef habitats inside the Lyme Bay and Torbay SAC are typically dominated by potting activity, there is the potential of static nets to be set inside the experimental units. Whilst the ecological impacts of static nets are unknown at this location it is perceived that their impact on benthic ecosystems is less severe. The deployment of static nets involves minimal contact with the benthos resulting in a low encounter rate with benthic commercial fishery species, such as crab and lobster. Despite this, potential exists for netting to have occurred within the experimental units. It is possible that the presence of baited whelk pots may influence results, attracting particularly crabs and lobsters away from experimental areas. However, whelk potting tends to focus on expanses of soft sediment, not reefs, and the majority of this activity is outside of the Lyme Bay and Torbay SAC. There is also no reason to believe that any influence that could possibly occur would do so unevenly across treatments. This study is therefore based on the assumption that the two fisheries do not extensively interact due to habitat availability and preference driving the behaviours of these fisheries. A significant amount of time and effort was spent engaging with local commercial potters so that all fishers were made aware of the project. However, some recreational potting is carried out inside the Lyme Bay and Torbay SAC and participating individuals were not specifically made aware of the project. Local commercial fishermen involved with the study acted as regulators of each experimental unit and a good relationship between lead researchers and fishermen meant any instances of incursion into the experimental units by unrecognisable vessels were reported. Instances of this were low throughout the duration of this project but the potential for additional gear being deployed inside the units, particularly from recreational fishermen should be acknowledged.

A study of this style requires agreement and compliance from commercial fishers. 500 m x 500 m Units were selected for their management practicalities and to reduce impacts on commercial fishermen. Larger units may have yielded more contrasting results over time, particularly within the areas of no potting, however this was considered not feasible for such a replicated design. It is accepted that uncontrolled inter-annual temporal variability could occur between both sample units and sampling times as is commonly the case with in situ ecological field studies. This may have contributed to significant differences between treatments not manifesting until the third year of the study.

7. Overall Conclusions

The results show a low density of potting has no impact on the seabed environment or target fishery species apart from a potential effect on one species, Ross coral. Currently the seabed within the MPA is recovering with Ross Coral being found very sparsely, but previously large Ross coral have been regularly recorded during the main Lyme survey, despite the existence of the potting fishery. This would suggest there is some compatibility between suitable levels of potting and the existence of Ross coral, but perhaps this activity slows the recovery of the species which has not been picked up in the time period of the experiment. Overall, therefore, the study provides evidence that existing low levels of potting within the Lyme Bay and Torbay SAC are generally compatible with the wider conservation objectives of the site. However, at high densities of pots, 30+ pots per 500 m x 500 m, indicative of maximum potting effort (higher than current potting effort in the Lyme Bay and Torbay SAC) and sustained over three years, potting can both damage the seabed ecosystem and reduce quality and quantity of target species. This is the first time a "threshold" has been demonstrated for commercial potting effort. The results provide evidence to support the management of commercial potting in the MPA, in order to maximise catch (total catch and economic return) and minimise ecological damage. This has been demonstrated by evidence of a relationship existing between potting density and quality of catch.

For any future management of commercial fisheries, lessons from this study can be learnt. The introduction of a voluntary Code of Conduct will initially encourage buy-in from local fishers and voluntary management of commercial potting may help mitigate against intensive commercial potting and encourage future sustainability of this fishery. Moving forward the following key questions remain: At present, how do local fishermen manage potting density and the number of pots are put down in some areas? Can mitigation approaches be first made to the voluntary Code of Conduct, to avoid certain areas being exposed to high potting density? If these questions can be answered then a well-managed commercial potting fishery can be achieved inside the Lyme Bay and Torbay SAC.

The impacted species observed in Study 1 should be considered in the context of the conservation objectives of the Lyme Bay and Torbay SAC. The objectives state that the extent, structure and function of the reef species assemblage should be maintained or restored. The results from this project can provide fisheries managers with information to assess the impacts of this type of fishing when assessing the conservation objectives of the Lyme Bay and Torbay SAC. At present over half of the UK's MPAs are being introduced to protecting seabed reef habitats and features. Such habitats are important for supporting commercial potting. If areas are protected against mobile forms of fishing then static fishing methods could increase. An increase in static gear effort has been anecdotally observed within other UK MPAs (Burke 2015), and so the evidence presented here should be used for proactive management of commercial potting activities.

The areas of no potting have provided some of the highest levels of protection in the Lyme Bay and Torbay SAC, as these areas have removed commercial potting activity, albeit voluntary within the wider SAC area that restricts bottom towed fishing. The efforts that have gone into introducing these areas should not be undermined and if possible these no potting areas should remain in place and continue to be monitored to improve the long-term data set from these areas, for ongoing and future assessments of recovery within the Lyme Bay and Torbay SAC. The feasibility of this continuation is currently being discussed with representatives from the local fishing community.

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